ALGAE OF THE HAWAIIAN ARCHIPELAGO. I

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The algae, particularly the seaweeds, of the Hawaiian Islands have attracted the attention of investigators for many years. In 1876 NORDSTEDT published a report upon the collections of BERGGREN ("De Algae aquae dulcis et de Characeis ex insulis Sandvicensibus a Sv. BERGGREN 1875 reportatis").

In 1881 a small list entitled "The algae of the Hawaiian Islands," by J. E. CHAMBERLAIN, appeared in THRUM'S *Hawaiian Almanac and Annual* for that year. In 1899 REINBOLD reported upon the collections of SCHAUINSLAND ("Meersealgen. Ergebnisse einer Reise nach dem Pacific; H. SCHAUINSLAND 1896–97." Abhandl. Naturw. Vereins Bremen 1899). The collector SCHAUINSLAND spent three months on the island of Laysan and made extensive collections of the algae of that island, of Oahu, and of the plankton between Oahu and Laysan. In 1901 Miss JOSEPHINE E. TILDEN published a popular article on "Algae collecting in the Hawaiian Islands" in *Postelsia*. This was an informal narrative of the visit made by herself and two other ladies to the islands in 1900. In 1902 Miss TILDEN published, in THRUM'S *Hawaiian Annual*, a list of 100 species entitled "Collection of algae from the Hawaiian Islands." In 1905 Miss MINNIE REED, science teacher at the Kamehameha Schools in Honolulu, published a valuable report in the *Annual Report of the Hawaii Agricultural Experiment Station*, entitled "The economic seaweeds of Hawaii and their food value."

In 1905 F. BRAND published "Anheftung der Cladophoraceen und über verschiedene polynesische Formen dieser Familie" (Beih. Bot. Centralbl. **18**:165–193). In 1905 E. LEMMERMANN published a very comprehensive paper ("Die Algenflora der Sandwich-Inseln," Bot. Jahrb. **35**:607–663), including plankton studies, and full records of the collections of SCHAUINSLAND.

In 1905 W. A. SETCHELL, who had made a short visit to the islands, published a paper on "Limu" (the Hawaiian word for seaweeds) in Univ. Cal. Pub. Bot. **2**:91–113. In 1910 Miss

TILDEN, in her "Minnesota algae, vol. I. Myxophyceae of North America," etc., included all available records of Hawaiian species and their distribution. In 1911 F. K. BUTTERS published "Notes on the species of *Liagora* and *Galaxaura* of the central Pacific" (Minn. Bot. Studies **4**:161–184). In 1917 the writer published a paper on "The seaweeds of Hawaii" (Amer. Jour. Bot. **8**:474–479. 1916).

The present paper is an effort to coordinate in a somewhat comprehensive and systematic form the scattered researches of nearly half a century, and to emphasize the ecological aspects of the Hawaiian algae. During a residence of 10 years in the islands the author has had opportunity to visit all of the larger islands, and to study the various algae habitats, from dredging operations along the reefs at a depth of 20 fathoms, up to the highest summits in the archipelago (nearly 14,000 ft.). His studies are incorporated in the present paper, but liberal use has been made of the investigations of others, particularly those of TILDEN, REED, and LEMMERMANN, to whom full credit is given for their pioneer labors.

Coral reefs

Because of their conspicuous situation along the coral reefs, large size, and economic value to the natives, the algae of the marine benthos flora have attracted particular attention. Seventy-five species, representing at least 40 genera, were habitually used for food by the ancient Hawaiians, and for these the natives had distinctive names.

Notwithstanding the relatively rich alga flora of the coral reefs, SCHIMPER'S statement that "in opposition to the terrestrial tropical marine vegetation is less luxuriant and apparently less rich in forms than is that of the temperate and polar regions" holds true for the Hawaiian Islands. Moreover, the rockweeds, kelps, and laminarias that dominate the coasts of the cold countries are conspicuously absent from the Hawaiian flora. The distribution of the Hawaiian marine algae is intimately associated with the coastal topography and the development of the coral reefs and shallows. The older islands of the group, which are also the lowest, owing to the combined action of erosion and subsidence, have the

most extensive coral reefs. At the other extreme stands Hawaii, the youngest, highest, and largest island in the archipelago, with practically no lowlands or coral beaches, and very little reef coral.

The oldest islands of the series are the tiny reefs and shoals dotted along an axis 1800 miles long, lying to the west of the main group. Although of little commercial value, and with a combined area of only 6 square miles, these little islands are of great interest from the standpoint of their alga flora. Nihoa, French Frigates Shoal, and Gardner are eroded volcanic blocks, 170–900 ft. high, rimmed with fringing coral. Laysan and Lisianski are elevated coral islands, 45–55 ft., with fringing reef. Pearl and Hermes, Midway, and Ocean are typical coral atolls. Maro and Dowsett's reefs have visible surf, but no exposed coral. The entire series, named in sequence from east to west, is Nihoa, Necker, French Frigates Shoal, Gardner, Dowsett's Reef, Maro Reef, Laysan, Lisianski, Pearl and Hermes Reef, Midway, Ocean. SCHAUINSLAND[1] spent three months on Laysan and made extensive collections of the marine flora, both plankton and larger forms, but no thorough explorations have been made of the algae on the other isles and reefs.[2] When such an exploration, or series of explorations, is made, there is not the slightest doubt that a large number of new forms will be revealed, and that very important contributions will be made to the algology of the Central Pacific region. The significant feature of this long chain of tiny islets is that it undoubtedly represents the various stages in the subsidence of a titanic submarine mountain chain.

Some of the representative forms collected by SCHAUINSLAND at Laysan, and therefore to be expected along the shores and in the lagoons of others of these westward isles, are *Chondrocystis Schaunslandii*, *Gomphospharia aponina*, *Coleosphaeriopsis halophila*, *Xenococcus laysanensis*, *Oscillatoria bonnemaisonii*, *Spirulina subtilissima*, *Phormidium laysanense*, *Lyngbya mucicola*, *L. meneghiniana*, *Aulosira Schaunslandii*, *Caulerpa pinnata*, *Stypopodium lobatum*, and *Liagora coarctata*.

[1] SCHAUINSLAND, H. H., Drei Monate auf einer Korallen Inseln. Bremen. 1899.

[2] MACCAUGHEY, VAUGHAN, The little end of Hawaii. Jour. Geog. 15:23–26. 1916; also Outstanding biological features of the Hawaiian Archipelago, in press.

KAUAI AND OAHU

Of the larger eastward islands, Kauai and Oahu are of particular note, as they have the largest coral reefs and support the most luxuriant marine flora. The reefs are all of the fringing and platform types, and vary in width from a few hundred feet to half a mile. Reefs are well developed along the southern or leeward shores of the two islands, and also, to a less degree, along the northern coasts. Oahu is practically encircled by coral, whereas Kauai has numerous coastal stretches entirely free from coral. The little island of Niihau, to the west of Kauai, has considerable coral reef. There are a number of regions along the Oahu coast which are especially favorable for collecting marine algae and for the study of their ecology. These are (1) the Waikiki region, between Honolulu Harbor and Diamond Head; (2) the Pearl Harbor region; (3) the Coral Plain and reef south of Ewa, between Pearl Harbor and Barber's Point; (4) the Waianae coast, which has extensive and well protected reefs; (5) the Wai-alua coast, which is not as well protected as that of Waianae; (6) the Kahuku region, with large sandy beaches and shoals; (7) the Ka-hana region, with drowned valleys and crescentic beaches; (8) Kane-ohe Bay, a beautiful body of water, 8 miles long and 3 miles wide, filled with coral islands and shoals; (9) Kai-lua and Wai-manalo, with lovely coral beaches and reefs; (10) the Koko Head and Mauna Loa district, with broad reef platforms half a mile wide. Most of the collecting by visiting algologists (TILDEN, SCHAUINSLAND, BERGGREN, etc.) was done along the Waikiki reefs, and also at Waianae. It has been the privilege of the author to visit repeatedly all of the reefs enumerated.

The following popular account[3] of a visit to a coral reef will serve to indicate the general features of this interesting life region.

> Arriving at a suitable location, where the water was only two or three feet deep, we anchored the canoe and prepared for wading. We were equipped with old shoes to protect our feet from the jagged, broken coral branches (which cause very painful and slow-healing wounds); with broad-rimmed hats to protect eyes, face, and neck from the intense glare of the sun and water;

[3] MACCAUGHEY, VAUGHAN, Coral reefs of the Hawaiian Islands. Jour. Geog. 14:252–255. 1916; also A survey of the Hawaiian coral reefs, in press.

with geological hammers for breaking off fragments of coral; and with sundry haversacks, bottles, wide-mouth vials, etc. With our water boxes as guides we wandered for three delightful hours over the ledges, knolls, and sandy pockets of the reef; collecting, exploring, and rejoicing in the luxuriant abundance of marine life of every form and color. Branches of living coral; many kinds of curiously shaped shells; bright spotted crabs and crustaceans of various sizes; spiny sea-urchins; spidery-armed brittle-stars; exquisitely beautiful hydroid colonies; purple and black sea-cucumbers; delicate marine algae of many genera, reds, browns, olives, and greens of varying tints, a kaleidoscopic succession of queer marine organisms.

ECOLOGICAL ZONES ON REEF

The typical fringing reef exhibits 5 distinct zones or areas of plant and animal life. This zonation is best developed on the reefs with wide lagoons and a well defined outer margin or rim.

1. *Beach or inshore waters.*—The shallow inshore waters, varying in depth from 6 to 36 inches, sustain a number of the quiet water forms, such as *Enteromorpha* spp., *Hypnea nidifica*, *Gracilaria coronopifolia*, *Chaetomorpha antennina*, *Ulva* spp., *Chondria* spp., *Liagora decussata*, etc. The bottom is of coral sand or mud, more or less contaminated with volcanic wash from the mountains. The nature of the bottom depends upon the proximity of streams and the strength of the surf. In many places (Kai-lua, Mo-kapu, Mana) the bottom is pure white coral sand, with practically no mud or rock. In other districts (Kalihi, Nu'u-anu, Kane-ohe) there are large "mud flats" exposed at low tide, and the bottom here is very muddy and rocky, with little sand. Every gradation may be found between these two extremes. At the mouths of streams, and at other places along the coasts where fresh water springs exist below the tide level, the inshore water is sufficiently brackish to prohibit the development of the strictly marine species.

2. *Partially submerged rocks.*—In some places the beach and shallow waters are devoid of rock masses, but as a general condition one finds partially submerged rocks scattered all along the coasts. These may be either close inshore, in the form of ledges or little cliffs, or may lie at varying distances from the shore. In any case they distinctly indicate, by their horizontal bandings of algal and hydroid life, the ranges of high and low tide. These rock masses

are either of consolidated reef coral or of black basaltic lava. Some algal species show a preference for the coral (*Sargassum*, *Gracilaria*, *Laurencia*), others for the lava blocks (*Gelidium*, *Ahnfeldtia*, etc.). The rocks may be in somewhat protected situations, or may be exposed to the full force of the surf. The alga flora will depend largely upon the situation of the rocks with reference to the surf. The following kinds occur on rocks which are exposed to the continual battering of the surf: *Gymnogrongus* spp., *Asparagopsis Sanfordiana*, *Codium* spp., *Sargassum* spp., *Dictyota acutiloba*, *Haliseris plagiogramma*, *Gelidium* spp., *Ahnfeldtia concinna*, *Porphyra leucosticta*. The controlling factor in the alga flora of the partially submerged rocks seems to be the circulation of pure, well oxygenated sea water. Rocks in stagnant or impure water support a scanty flora as compared with those in surf-swept localities.

3. *Pools.*—Passing out beyond the rock litter we come to a zone characterized by numerous pools or pockets. These cuplike depressions in the lagoon floor vary in size from little pockets a meter in depth and diameter to large pools 5–10 m. in depth and diameter. The pools are easily distinguished by the darker tint of their waters as contrasted with that of the shallow lagoon. These pools in the floor of the lagoon are not to be confused with the "tidal pools" along the beaches. The lagoon pools are inhabited by a variety of algae and animals that prefer these shadowy havens to the exposure of the shallows or the outer reef. The bottom of the pool may be covered with clear coral sand, or coral débris, or masses of growing coral; its alga flora will depend upon its depth and the resultant intensity of illumination.

The following are typical forms that inhabit the lagoon pools: *Lithothamnion* spp., *Corallina* spp., *Peyssonnelia rubra*, *Grateloupia filicina*, *Ceramium clavulatum*, *Amansia glomerata*, *Polysiphonia* spp., *Chondria tenuissima*, *Laurencia* spp., *Martensia flabelliformis*, *Champia compressa*, *Wrangelia penicillata*, *Galaxaura lapidescens*, *Padina pavonia*, *Sphacelaria furcigera*, *Hydroclathrus cancellatus*.

4. *Lagoon.*—The entire region between the beach line or strand and the seaward rim of the reef is properly the lagoon, but for the purposes of this paper the term will be restricted to the deeper waters, which usually lie about midway between the beach and the

reef rim. As one approaches the lagoon, wading is no longer possible, the water is 3–10 m. or more deep, but again becomes shallower as the outer edge of the reef is reached. The water of the lagoon is placid, clear, and very transparent, so that the bottom receives good illumination. Although a number of the smaller algae grow upon the floor of the lagoon, the region is comparatively barren as compared with the shallower waters on either side. The lagoon floor is a region of coralline and animal life, rather than of the larger plant life. The quantities of sand that are constantly washed over the floor from the disintegrating reef rim render it difficult for plants to maintain themselves. Probably if conditions for collecting on the lagoon floor were more favorable, a larger number of species would be found than are apparently present.

5. *Reef rim.*—Upon rowing across the lagoon to the outer rim of the reef, one comes to shallow water, where the surf breaks, and where wading is possible. This zone is a favorite fishing ground of the native Hawaiians, and it abounds with both animal and plant life. The highest portions of the rim may be practically exposed at low tide, although at high tide they will be covered by 18–24 inches of water. The rim of the reef is by no means regular or symmetrical; there are many indentations, crags, débris slopes, pools, hummocks, and sandy spots all along the outer margin. Almost all of the visible coral in this region is living coral, associated with an abundance of corallines, bryozoans, hydroids, red algae, and other forms of life. Some of the algae that are confined largely to the outer reef rim are *Haliseris*, *Dictyota*, *Codium*, *Asparagopsis*, *Gymnogongrus*, *Porphyra*, *Turbinaria*, *Gelidium*, etc. Many of the species that inhabit these surf-churned waters are not the tough, cartilaginous forms, but very delicate and fragile species, that apparently survive the wave action because of their very delicacy. This is particularly true of some of the finer red algae.

TIDES

The situation of the Hawaiian Islands, in the great stretches of the North Pacific, is such that the tides are very small; in contrast with the tides usual along continental coasts they are exceedingly small. The average rise and fall lies within a vertical range

of 18–24 inches. The difference between high and low tide is so small that there is almost a complete absence of the strongly developed tidal zonation so characteristic of many continental shores. However, on the broad platform reefs, like those near Pearl Harbor, Waialae, and Mauna-lua, this difference is sufficient to expose much of the reef surface at low tide. At this time the reef consists of an irregular series of pools, cut off from one another by the rocky platform, which has only 2–3 inches of water on it. Protruding areas of the reef are wholly exposed to the air, and on their knobs or knolls only the hardy species of algae can exist. Out toward the edge of the reef a shallow lagoon, or series of lagoons, may persist, unemptied by the lowest tides. This is the ideal time for collecting, as one can travel afoot far out to the rim of the reef and easily procure material which at high tide is hidden beneath the surf and foam. To get the full advantage of the low tide one customarily begins work when the tide is about half run out, and then follows the ebb out to its maximum. This gives a working period of 4–5 hours.

CORALLINE ALGAE

Highly important among the Hawaiian marine algae are the coralline or "stony" algae or nullipores. A number of genera (*Lithothamnion*, *Corallina*, *Mastophora*, and others) are abundant on the Hawaiian reefs, and have undoubtedly been highly effective in reef building. The importance of these lime-secreting algae was overlooked by the earlier students of the coral reefs, but is now beginning to receive adequate consideration. As MAYER[4] states:

> The most striking feature which distinguishes the Pacific reefs is the development of a ridge which actually projects half a foot or more above low tide level and extends along the outer seaward edge of the reef-wall wherever the breakers dash. In the Paumotus this ridge is dull reddish pink in color, and it is composed of a mass of stony seaweeds or nullipores of the sort called *Lithothamnion*, and also of bryozoa which are remarkable lime-secreting organisms related more closely to the worms than to any other form of the animal kingdom.
>
> This *Lithothamnion* ridge thrives only where the breakers strike in full force upon its living barrier, and it serves as the chief protector of the island, breaking the force of every wave that approaches the windward shore.

[4] Popular Science Monthly **85**: 209–231. 1914.

HOWE,[5] in a digest of our present knowledge of the lime-secreting algae as reef makers, shows that in the famous boring at Funafuti, which was driven to a depth of 114.5 ft., *Lithothamnion* was found to be more or less abundant through the entire length of the boring; *Halimeda* was locally very abundant from 28 to 1096 ft. According to the same paper *Lithothamnion* is now recognized to be a dominant reef builder in the reefs of Fiji, Gilberts, Dutch East Indies, Bermudas, and other groups.[6] He states that the lime-secreting seaweeds flourish and are effective reef builders in greater depths than is the case with corals. There are numerous records of these forms at depths of 100 fathoms, *in situ*, and occasionally at 250–350 fathoms, whereas 25–40 fathoms is the greatest depth attained by the reef-building corals. HOWE continues:

> Besides flourishing in greater depths than the corals, the lime-secreting seaweeds are much less dependent upon high temperatures than are the corals. . . . . The coralline algae are, locally at least, abundant from 73°5′ south latitude to 79°56′ north latitude. . . . . He specifies the seas off the coasts of Spitzenberg, Nova Zembla, Iceland, Greenland, and Norway, where banks of *Lithothamnion* cover the bottom for areas of many square miles. . . . . The massive beds of *Halimeda opuntia* off the Florida Keys (the same species . . . . that is filling the lagoons of some of the South Sea atolls) are striking, as are the banks of *Goniolithon strictum* in the Bahamas, and reefs of *Lithophyllum antillarum* and *L. daedaleum* along the shores of Porto Rico. . . . . The lime-secreting plants appear to be much more generally and widely distributed, both horizontally and vertically, than are the corals.

The Hawaiian corallines inhabit the shallow waters, as well as occurring at considerable depths. In the former situations they form beautiful rose, purple, and lavender incrustations. On the faces of cliffs that are washed by the sea the incrustation appears as a conspicuous rose or purple band, extending from high tide mark or the uppermost wash of the surf, down to the zone of minimum illumination. The lower margin of the coralline zone has not been investigated in the Hawaiian Islands, but it undoubtedly reaches as great depths as in the island groups already cited. The upper margin is often somewhat above high tide mark, as these

[5] HOWE, M. A., Building of coral reefs. Science, N.S. **35**:837–842. 1912.

[6] See also SEWARD, A. C., Algae as rock-building organisms. Science Progress **2**:10–26. 1894.

algae are able to live even if they receive only intermittent spray wash. In this coralline zone are many of the calcareous hydrozoa.

TIDAL POOLS

Along the rocky coasts, where there are extensive shelves or ledges of lava or uplifted coral limestone, tidal pools are of common occurrence. The pools that lie nearest the water line are filled at every tide; indeed, many lose their identity as pools at each tide. Those at higher levels, and farther from the water line, may be filled only at times of very heavy surf, and dry up for considerable intervals. These variable conditions greatly affect the alga flora. The pools vary in size from mere puddles to large basins 10–20 m. long and 3–5 m. in depth. These large perennial basins support an alga flora very similar to that of the shallow lagoon waters. Excellent examples of tidal pools occur along the southern coast of Kauai, the Maka-pu'u region of Oahu, the north coast of Molokai and Maui, and along the Kona coast of Hawaii. Some of the algae common in the ordinary tidal pools are species of *Limnothamnion*, *Wrangelia*, *Liagora*, *Padina*, *Ectocarpus*, *Sphacelaria*, *Halimeda*, *Caulerpa*, *Cladaphora*, *Chaetomorpha*, *Enteromorpha*, *Monostroma*, *Calothrix*, *Scytonema*, *Hormothamnion*, *Hydrocoleus*, *Lyngbya*, *Phormidium*, *Oscillatoria*, etc.

CORAL REEFS ON OTHER ISLANDS

Special mention has been made of the reefs of Kauai and Oahu. The islands of Molokai, Maui, Lanai, and Ka-hoo-lawe all possess some coral reefs, but nowhere is the development of the alga flora as great as upon Oahu. The island of Molokai, both windward and leeward sides, ranks first among the 4 islands enumerated. The island of Hawaii, with an area larger than the combined area of all the other islands, is the poorest in marine algae. In fresh water species, however, it takes precedence over several of the smaller islands. The coasts of Hawaii are rugged and precipitous, and the deep offshore waters are not favorable for algae.

Taro loi and rice fields

Turning now to the habitats of the fresh water flora, we consider first the taro loi. The Hawaiians and Chinese raise the taro plant

(*Colocasia esculenta*) in irrigated patches called "loi." These are located on the lowlands and valley floors. Water is skilfully diverted from the mountain streams, and spread in a thin sheet over the loi. These tiny fields are each only a fraction of an acre in area, and many are only 20–30 ft. each way. The bottoms and low retaining embankments are composed of black volcanic alluvium. The loi are not continuously under water, but are flooded only at certain stages in the development of the taro. In this way each loi is at one time a shallow pond 6–12 inches in depth, at another a sheet of very soft, water saturated mud, and at another a sheet of fairly compact mud. These loi are notable habitats for the various fresh water algae, which occur in great variety and luxuriance. The algae may be found, according to their specific habitats, either floating on the surface of the water, free swimming in the water, growing upon the muddy bottom, epiphytic upon the stems of aquatic plants, or growing along the moist margins of the embankments, near the water's edge.

In recent years many of the taro patches have been converted into rice fields by the Chinese. The general conditions of irrigation, so far as influencing the alga flora are concerned, are practically the same for the rice as for the taro. Luxuriant growths of many fresh water species may be found in the rice fields. Some of the representative species occurring in these situations are as follows:

FLOATING AND FREE SWIMMING.—*Chroococcus*, *Raphidium*, *Scenedesmus*, *Gloeothece*, *Aphanothece*, *Merismopodium*, *Xenococcus*, *Lyngbya*, *Anabaena*, *Scytonema*, *Hydrodictyon*, *Conferva*, *Ulothrix*, *Cladophora*, *Spirogyra*, etc.

EPIPHYTIC.—*Chamaesiphon*, *Lyngbya*, *Coleochaete*, etc.

ON BOTTOM OR MARGIN.—*Lyngbya*, *Nostoc*, *Anabaena*, *Scytonema*, *Stigonema*, *Calothrix*, *Rivularia*, *Gobium*, *Draparnaldia*, *Oedogonium*, *Bulbochaete*, *Nitella*, *Chara*, *Mougeotia*, *Zygnema*, etc.

Ditches and flumes

A habitat for many kinds of algae is the irrigation ditch or flume. The very general use in the islands of irrigation water for the raising of taro, rice, sugar cane, and other crops has led to the development of elaborate systems of ditches and flumes. The inner walls and margins of these water channels support a diversified algal flora, despite the intermittent nature of the water supply. Many of the flumes are constructed of rough wooden planking,

which often has sufficient leakage to stimulate extensive algal growths, either pendent from the under side of the flume or in the drip zone beneath it. Genera that are of frequent occurrence in the ditches and flumes are *Gloeocapsa*, *Aphanothece*, *Oscillatoria*, *Spirulina*, *Phormidium*, *Lyngbya*, *Nostoc*, *Anabaena*, *Cylindrospermum*, *Scytonema*, *Tolypothrix*, *Ulothrix*, *Stigeoclonium*, *Nitella*, *Chara*, *Zygnema*, *Spirogyra*, etc.

Caves

There are many caves in the Hawaiian mountains. Some are of vast size, but the majority are relatively small. They occur at all elevations, from sea level to the highest summits, and are invariably due to volcanic activity in former times. Many contain pools of water; those at sea level frequently have salt or brackish water. The walls of the cave are usually moist, especially around the mouth, due to seepage from above. The conditions of continuous moisture and sufficient light, which prevail near the mouth of the cave, are favorable for the development of algae. Luxuriant growths, particularly of the Cyanophyceae, occur in these places. Representative species which inhabit these localities are *Gloeocapsa quaternata*, *Aphanothece Naegeli*, *Oscillatoria sancta*, *O. formosa*, *Spirulina major*, *Phormidium papyraceum*, *Nostoc* spp., *Anabaena variabilis*, *Scytonema varium*, *S. ocellatum*, *Fischerella ambigua*, *Characium minutum*, *Ulothrix minutula*.

Some typical Hawaiian caverns which support an abundant algal flora are those of Ha-ena, Kauai; Nu'u-anu, Manoa, and Maka-pu'u, Oahu; Kau-po region of Hale-a-ka-la, and Hana region, Maui; Hilo and Ka-u regions of Hawaii. Innumerable smaller caverns are scattered throughout the mountainous regions of all the islands.

Mountain streams

The rainfall on the upper slopes (2500–6000 ft.) of the Hawaiian mountains is torrential. This has carved deep valleys, penetrating into the heart of the mountains. These valleys vary in length from a mile to 10–12 miles. In width they range from narrow, rock-walled, sunless gorges to great amphitheaters, several miles in diameter, and rimmed by tremendous precipices. In the floor of each valley is a narrow stream, rarely more than 12 ft. in width.

The slope of most the valleys is so steep, and the drainage basin so restricted, that the run off is extremely rapid, and the fluctuations in stream volume are very pronounced. The upper course of the stream, through the rain forest, is littered with large lava boulders, dotted with small pools, and interrupted by numerous cascades. The waterfalls vary in height from a few feet to 1500 ft. These mountain streams, owing to their intermittent nature, are not very favorable for the algae, and luxuriant growth is rare. The contrast between the abundant algal flora of a flooded taro loi or rice field, on the warm lowlands, and the paucity of forms inhabiting a cold, intermittent mountain stream, is very striking. On the other hand, although the algae are not abundant, they are present in moderate quantities and in considerable diversity.

On the moist earth along the banks of the stream, on the rocks in the bed itself, and in the frequent pools one finds such algae as *Gleocapsa quaternata*, *Aphanothece Naegeli*, *Phormidium*, *Lyngbya*, *Anabaena*, *Scytonema rivulare*, *Tolypothrix distorta*, *Dactylococcus infusionum*, *Dictyosphaerium pulchellum*, *Raphidium polymorphum*, *Pediastrum*, *Conferva*, *Ulothrix*, *Stigeoclonium*, *Draparnaldia macrocladia*, *Oedogonium*, *Bulbochaete*, *Cladophora nitida*, *Nitella haviensis*, *Xenococcus Kerneri*, *Characium groenlandicum*, *Closteriopsis longissima*, *Schroederia setigera*, *Salpinocoeca minuta*, *Dinobryon sertuaria*, *Hemidinium nasatum*, *Asterionella formosa*, *Triploceros*, *Melosira*, *Cyclotella*, *Cymatopleura*, etc. The faces of the waterfalls, and the dripping cliffs immediately adjacent, are the habitats of such forms as *Gloeocapsa magma*, *Oscillatoria* spp., *Spirulina major*, *Nostoc* spp., *Scytonema varium*, etc.

Hot springs and thermal waters

The only waters in the Hawaiian Archipelago that have temperatures higher than that of the atmosphere are those in the vicinity of the active volcano Kilauea, Hawaii. There are a number of warm pools and springs in the Puna district, and these evidently all receive their heat from the subterranean molten lavas of Kilauea. The temperatures of these waters vary between 30 and 35° C. These warm pools contain a luxuriant algal growth, especially in the form of a coating over the rocks that form the sides and floors of the pools. Representative thermal species are *Fischerella thermalis*,

Gloeocapsa thermalis, Haematococcus thermalis, Microcoleus paludosus, Plectonema nostocarum, Schizothrix havaiensis, Scytonema azureum.

Summit bogs

A type of habitat differing markedly from those that have been described are the five bogs which occur on the summits of Waiale-ale, Kauai, Ka-ala on Oahu, East Molokai, West Maui, and the Kohala Mountains of Hawaii.[7] These bogs lie at an elevation of 4000–6000 ft., in a zone of almost continuous cloud and rain. The annual precipitation in these regions amounts to several hundred inches, perhaps as high as 500. The soil is perpetually saturated, and is covered with a blanket of alpine sedges, rushes, grasses, mosses, and liverworts. In this substratum, and in the relatively small and infrequent pools that occur here and there on the surface of the bog, there is a considerable variety of algae. It is to be regretted that the alga flora of the summit bogs has not received careful investigation. The higher plants that inhabit these regions are mostly endemic species and varieties, and it is probable that a proportion of the algae would also prove to be endemics. The blue-greens are the dominant group.

Brackish waters

At various places along the coasts, but particularly where the larger streams empty into the sea, are areas of brackish water. These may be either the actual mouth of the stream itself, lagoons, or swamp lands. In any case, these waters are inhabited by species which differ both from the strictly fresh water forms on the one hand and the marine species on the other. Many of the brackish water forms are used by the Hawaiians as food. Typical forms of these waters are *Enteromorpha* spp., *Oedogonium obsoletum, Chaetomorpha pacifica, Cladaphora* spp., *Nitella havaiensis*, etc.

Halophytes

LEMMERMANN lists a few halophytes from the "Salt Lake" Crater of Moana-lua,[8] and from the Laysan lagoon, which is about

[7] MACCAUGHEY, VAUGHAN, Vegetation of the Hawaiian summit bogs. Amer. Bot. **22**:45–52. 1916.

[8] This is no longer highly saline, as an artesian well has been bored in its bottom, and the lake converted into a fish pond.

three times as salty as sea water. The species are *Amphora ovalis* var. *pediculis*, *Lyngbya mucicola*, *Nitzschia angularis*, and *Coleosphaeropsis halophila*. The Laysan lagoon is the only known place in the archipelago possessing water of greater salinity than that of the sea, although of course the evanescent tidal pools attain a high degree of salinity in their later stages.

Fish ponds

Many of the free floating and filamentous algae are very abundant in the "loko" or fish ponds. These are shallow waters along the coasts that have been cut off from the open sea by means of heavy stone walls. The wall usually extends out from the land in the form of a crescent, pierced here and there by grated openings or gates, which permit the passage of the tides and very small fish, but which effectually retain the larger fish. The water within the pond is not disturbed by the surf, and the life conditions are more tranquil than those of the lagoon or sea. In ancient times some of the loko were utilized by the Hawaiians for a crude kind of limu culture. *Enteromorpha* and other coarse filamentous forms often form extensive floating mats on the waters of the loko. These ponds are most numerous on the islands of Oahu and Molokai, and have a combined area of many hundreds of acres.

Phytoplankton

The author has made no studies of the Hawaiian phytoplankton and so can only summarize here the extensive studies of SCHAUINSLAND and LEMMERMANN. The totals given by the latter authority are as follows:

	In Pearl Harbor	Between Hawaii and Laysan	Open Roadstead at Laysan
Schizophyceae.....	0	7	0
Chlorophyceae.....	0	2	0
Silicoflagellatae.....	0	3	0
Peridiniales.....	11	29	4
Bacillariales.....	11	10	12
Totals.....	22	51	16

The number of species of the last two groups, excluding duplicates, was 33 Peridiniales and 31 Bacillariales. The Hawaiian waters await an exhaustive study of their plankton; such a study will undoubtedly bring to light much new material of great interest.

Deep water forms

There have been no large investigations of deep water forms in the vicinity of Hawaiian waters comparable to those made in other parts of the ocean. The Hawaiian Islands all slope off very abruptly into deep water. There is little evidence of shelves or platforms. The outer faces of the coral reefs are all very precipitous, in striking contrast with the gentle slope of the inner or lagoon face. By some geologists the islands have been compared to the summits of a row of obelisks. The inter-island channels are very deep. The following table will make clear the extensiveness of the deep waters in the immediate vicinity of the islands:

Channel between Kauai and Oahu.....		1872	fathoms or	11,232	ft.
" "	Oahu and Molokai.....	384	"	2304	"
" "	Molokai and Maui.....	135	"	810	"
" "	Maui and Hawaii.....	1032	"	9192	"

Endemism

The endemism which is so striking a feature of the terrestrial flora is exhibited to only a very minor degree by the algae. It is difficult to make any very comprehensive statement on this subject, as our knowledge of the algal flora of other Pacific Islands is still very incomplete. The following are typical forms which may be considered endemic in the present status of our knowledge: *Corallina sandwicensis*, *Mastophora tenuis*, *Laurencia nidifica*, *Plocamium sandwicense*, *Sargassum obtusifolium*, *S. polyphyllum*, *S. densum*, *S. incisum*, *Zygnema spontaneum*, *Oedogonium globosum*, *Draparnaldia macrocladia*, *Conferva sandwicensis*. Most of the algae are either cosmopolitan species or else widely distributed in many tropical and subtropical waters.

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